From the desk of...

The description of fluid-induced whirl

by ***Donald E. Bently***
Chairman and Chief Executive Officer
Bently Nevada Corporation
President, Bently Rotor Dynamics
Research Corporation

Oil whirl is universally described as a forward circular orbit at a nearly constant frequency, typically at 0.40 to 0.46 of rotative speed. The term "oil whirl" was originated by H. Poritsky forty years ago.

Bently Rotor Dynamics Research Corporation has been teaching the algorithm for fluid-induced whirl and whip for over ten years, but I fell into the common trap of describing machinery behavior almost entirely by frequency. I chide others for describing malfunction by frequency alone, and nearly made the same mistake.

The rest of this description is

"... with increasing orbit size as rotor speed increases."

The proper description for simple fluid-induced whirl consists of frequency & amplitude equations. The frequency part is

$$\omega = \lambda\Omega(1 - \text{stuff}) \qquad (1)$$

where:

ω = forward circular whirl frequency
Ω = rotative speed
λ = fluid circumferential average velocity ratio

In a very simple system, "stuff" is $\dfrac{D_S}{D_B}$ where D_B is the damping of the element that has the fluid swirl (usually a bearing), and D_S is the damping of the rest of the system. "Stuff" gets more complicated for larger systems and also for the fluid whip situation, but equation (1) is ok for starters.

The amplitude part of the algorithm, at which the rotor orbits, is determined by the nonlinearity of the bearing or seal fluid film stiffness, or other rotor-to-stator interface. Typically, this is of the form shown in Figure 1 and Equation 2.

$$K_B = \frac{K_{BO}}{(1-e^2)^{\frac{3}{2}}} \qquad (2)$$

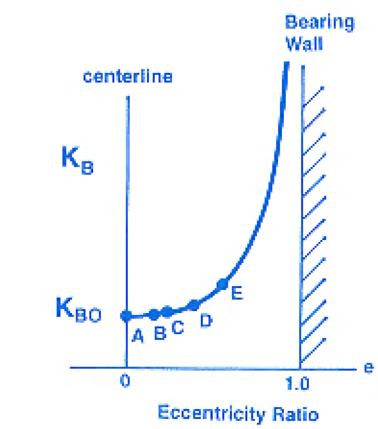

Figure 1
Direct (radial) stiffness of the fluid film as a function of eccentricity ratio.

where:

K_B is the bearing or seal fluid film direct (radial) stiffness as a function of eccentricity ratio e.

K_{BO} is the fluid film direct stiffness of a concentric rotor at zero eccentricity, typically as in Figure 1.

M is rotor effective (modal) mass.

e = whirl-orbit-radius to radial-clearance eccentricity ratio, or e = whirl-orbit-diameter to diametral-clearance eccentrity ratio.

The fluid-induced instability always satisfies equations 1 and 3 by adjusting orbit size per equation 2. Whirling occurs when the lateral mechanical resonance frequency "critical"

$$K_B = \omega^2 M \qquad (3)$$

and the fluid-induced resonance frequency, equation 1, occur at the same frequency.

It is obvious that, as rotative speed Ω increases, whirl frequency ω increases, which is the result of the higher eccentricity of a larger orbit, and that is the limit cycle of the fluid-induced whirling.

The entire verbal description of the symptom fluid-induced whirl is, therefore, **a forward circular orbit at a nearly constant frequency, typically at 0.40 to 0.46 of rotating speed, with increasing orbit size as rotative speed increases (Figure 2).**

References:

1. Poritsky, H., Contribution to the Theory of Oil Whip, Trans. of the ASME, v. 75, No. 6, 1953.
2. Muszynska, A., Bently, D. E., Fluid-Induced Instabilities of Rotors: Whirl and Whip – Summary of Results, Noise and Vibration '95 Conference and Workshop, Pretoria, South Africa, 1995.
3. Bently, D. E., Muszynska, A., Role of Circumferential Flow in the Stability of Fluid-handling Machines, NASA CP 3026, 1988.

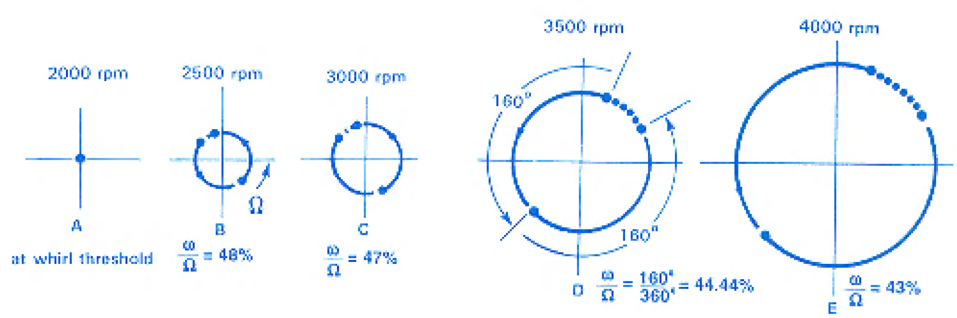

Figure 2
Typical rotor orbits at fluid whirl instability.